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SYNTHETIC APERTURE RADAR MISSION STUDY REPORT

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Steven Bard, Editor

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EXECUTIVE SUMMARY

This report reviews the history of the LightSAR project and summarizes actions the agency can undertake to support industry-led efforts to develop an operational synthetic aperture radar (SAR) capability in the United States. This is an interim report. After appropriate consideration of inputs from the science community and industry SAR users and hardware providers, a final report will be prepared.

The science benefits and justification of a U.S. SAR mission are compelling. The Earth Science community has identified key spaceborne SAR measurements as an important part of NASA's post-2002 Earth Science Enterprise (ESE) objectives. The report of the Workshop on NASA Earth Science Post-2002 Missions concludes that, "a capability to carry out SAR interferometry belongs high on NASA's priority list for systematic measurement." In addition, the National Science Foundation (NSF) has recently identified the need for a spaceborne interferometric SAR (InSAR) mission as a key element of their EarthScope initiative designed to greatly increase our understanding of the structure, evolution and dynamics of the North American continent. SAR measurements also address Cold Land Processes research, which was identified as an essential Earth Science theme to be addressed by the post-2002 suite of NASA Earth Science missions.

Is there sufficient synergy between scientific and commercial SAR applications such that industry would be interested in co-funding a SAR science mission? Reviewing the history of the LightSAR project demonstrates that there is no such interest because market potential for the data and the resulting return on investment are very limited. Even with commercial enhancements, the LightSAR experience shows that government dependence on a substantial industry investment in a SAR mission is unrealistic at this time. For example, adding a second radar frequency and high-resolution capability greatly increases the market potential of SAR data and information products. However, the substantially increased cost of such a multiparameter system combined with the high market risk render projected returns on investment highly uncertain. This was a significant factor that led to just a single industry proposal being submitted in response to the 1999 NASA Announcement of Opportunity (AO) for a LightSAR mission partner. NASA did not select that proposal primarily because it was based upon a fragile business plan that posed an unacceptable financial risk to the government.

The scientific, commercial, and technology objectives of LightSAR remain important objectives. Industry is still interested in participating and moving forward with a U.S. spaceborne SAR mission. Furthermore, technology developments and risk mitigation by the LightSAR project and related efforts have significantly advanced the maturity level of critical technologies to the point where they no longer present significant risk. The LightSAR objectives can be achieved, given an approach that reduces the financial risk to both government and industry, and addresses a broad range of valuable science and commercial applications.

With the above historical perspective, the agency continues to study various SAR mission concepts and collaboration and partnership approaches. This report describes some emerging concepts that are representative of the range of options being considered, each addressing a different balance of science and commercial interests. These options include: 1) a science-focused mission, with possible small commercial enhancements, funded primarily by the government; 2) a dual use system with a highly capable dual frequency radar that has broad scientific and commercial utility, funded primarily by the government, with an industry partner for commercial operations, including data processing and distribution; and 3) a commercially funded mission.

The first concept is a primarily science-focused mission that emphasizes systematic science measurements identified by the Earth science community as part of NASA's post-2002 ESE objectives, particularly InSAR. The U.S. solid earth science community has been urging NASA to fly an InSAR science mission since the first dramatic demonstration of the science possibilities using foreign SAR data in 1993. The recent NSF agency endorsement of such a mission as an essential element of their EarthScope initiative is the culmination of years of experience working with limited data available, and refinement of mission concepts through trade studies in the science area. By NASA funding the entire mission, except perhaps for modest contributions to a portion of the ground segment and operations by partnering agencies, there is potential for building markets for science and value-added data, and infrastructure, for future more heavily commercial SAR missions. This concept could embrace technological and commercial innovations as building blocks to more intensely commercial missions in the future, while satisfying an important segment of the Earth science community now.

The second concept is a dual-frequency, polarimetric, interferometric SAR that has broad scientific, environmental preservation, and commercial utility, and is funded primarily by the government. By reducing financial risk and boosting commercial potential relative to the LightSAR approach, this concept is expected to foster a realistic resource-sharing partnership that mutually benefits both the government and industry. This system is capable of addressing the post-2002 NASA ESE SAR measurement objectives (including the LightSAR science objectives), the NSF/ EarthScope InSAR science objectives, environmental management objectives (e.g., rapid oil spill response), plus a broad range of commercial applications such as mapping, surveillance, forestry, agriculture, resource exploration, and land use and urban planning. A breakthrough feature of this system that greatly reduces potential for tasking conflicts between science and commercial applications is the ability to operate both frequencies independently and simultaneously.

In this concept, industry would lead, and be encouraged to contribute a resource-share investment in the ground segment development and operations, which is the segment of the mission that has the greatest potential for generating revenue and promoting market growth. For the rapid oil spill emergency response needed for this concept, the preliminary ground segment and operations concept includes a primary command/control and receiving station, and a long term data archive, located in Sioux Falls, South Dakota, a northern latitude ground station located in Fairbanks, Alaska, and rapid response processing at a proposed Environmental Response Data Center located in Houston, Texas to enable information to be delivered to oil spill response teams in time to influence critical spill mitigation decision making. Also, remote sensing centers at Mississippi Universities could participate by the addition of a low cost receiving station that would provide student and faculty access to SAR data to support Gulf region applications.

This overall concept has the potential to emulate the many examples of successful industrial segments initiated by government investments, such as GPS, Internet, and commercial space telecommunications. In each case, the government funded and retired the start up risks and enabled commercial ventures to create new industries. These new industries became engines for national growth, a source for talented workforce, and a platform for other emerging products and services.

The capability to support rapid response to oil spill emergencies and environmental preservation has led to the suggestion that NASA explore collaboration with the Oil Spill Liability Trust Fund (OSLTF) to provide the government funding for this option. The OSLTF was established as a result of the Oil Pollution Act of 1990 (OPA 90). Appendix D includes endorsement letters from Texaco and other petroleum industry organizations supporting this mission concept and the NASA-OSLTF collaboration approach.

The third concept is a commercially funded mission. If the private sector were to credibly demonstrate their interest and ability to finance and develop a commercially funded SAR mission, NASA would certainly consider purchasing data if it meets NASA's science needs. However, at this time there is no reliable evidence that the private sector will fund the development of a SAR mission. If NASA waits and depends on the private sector to develop such a mission, there is a significant risk of losing the opportunity for obtaining critical Earth science data in the near future, including InSAR data urgently needed by the Earth science community. If NASA instead steps up to take a leadership role in developing a SAR mission now, and fosters growth of the commercial market and value-added capabilities, it may help make it possible for U.S. industry to fund a commercial SAR mission in the future, with NASA as a data customer.

All the proposed SAR mission concepts include observations that will profoundly improve our understanding of Earth. To a greater or lesser degree these include assessment of natural hazards, environmental management, and a wide range of commercial applications. The development of a mission awaits the formation of the right collaborations and partnerships. NASA plans to continue to define and evaluate SAR mission concepts, collaborations, and implementation approaches, and to continue preservation of the technology required to field a world class system that will assure the United States leadership position in radar remote sensing. This includes exploration of resource-sharing arrangements with the private sector and fostering commercialization of the system. It also includes exploration of collaboration with other government agencies and foreign space agencies.

NASA will disseminate its plans for a SAR mission as widely as possible. A SAR Users' Workshop held in conjunction with Texaco on January 19-20, 2000, included representation from the petroleum, agriculture, forestry, remote sensing, value-added, and Aerospace industries, as well as government agencies. The workshop proceedings are available at: http://southport.jpl.nasa.gov/SAR_Users_Workshop/. This workshop built upon results of an earlier workshop held for petroleum industry remote sensing data users at Texaco, on December 2, 1999. The consensus at these workshops was that the participants supported moving forward now with the dual-frequency, polarimetric, interferometric SAR concept described above. As a result, a SAR Information Users Working Group is being formed to foster advocacy of this mission, enable users to influence the system capabilities and design, and to continue government-private sector dialogue on how to proceed.

This effort is expected to culminate in the development of a SAR mission. By taking an aggressive and proactive role in the development of such a mission now, NASA will be affirming U.S. leadership in SAR science, technology, and commercial remote sensing, and advance U.S. commercial competitiveness ahead of foreign SAR missions currently being planned and developed. Development of a U.S. operational SAR mission is urgently needed to fill the void in SAR scientific, environmental preservation, and commercial applications data, while also fostering market growth that may enable the possibility of a future commercially-funded SAR mission.

1.0 INTRODUCTION

The LightSAR project was an attempt by NASA to develop and launch a free-flying, Earth-observing, lightweight, synthetic aperture radar (SAR) mission in an innovative partnership with industry. It was part of NASA's long term investment in the development and prosperous use of imaging radar science and technology in the public and private sector. Past spaceborne radar missions have established the vast potential of imaging radar for expanding scientific knowledge of the Earth and planets. LightSAR was conceived as the next step forward to deliver exciting Earth science data that fulfills a fundamental part of NASA's Earth science strategic plan, and to demonstrate new remote sensing capabilities that will open new markets and lead the next level of expansion for the U.S. commercial remote sensing industry.

Significant progress was made in the LightSAR program, including the release of an Announcement of Opportunity (AO) soliciting proposals to implement the project. However, only a single industry proposal was received. After thorough evaluation and careful deliberation, NASA decided not to select the proposal for award.

This report was prepared to support NASA's response to the request for information in the Conference Report (House Report 106-379) accompanying H.R. 2684, the FY2000 VA-HUD and Independent Agencies Appropriations bill. This report reviews the history of the LightSAR project, including the accomplishments and lessons learned from that effort, and the actions the agency can take to support an industry-led operational SAR capability in the United States.

The agency is continuing to study various SAR mission options. The result of these studies is expected to lead to the development of a SAR mission. The objectives of this mission are to: (1) develop and launch a U.S.-led, free-flying, synthetic aperture radar (SAR) system; (2) conduct important scientific investigations that address NASA's post-2002 SAR science measurement needs; (3) produce data that enable a broad range of environmental management and commercial remote sensing applications, enabled by an Earth-observing SAR; (4) demonstrate advanced technologies that reduce the cost and enhance the performance of future SAR missions; and (5) enable U.S. industry to open new markets and create long-term businesses that will become sustained providers and consumers of valuable science and commercial SAR data. Such a mission would be the preeminent space radar remote sensing system and affirm U.S. leadership in radar science, technology, and commercial applications

While NASA's scientific interests are primarily in the medium resolution L-band data, LightSAR studies done by industry identified substantial commercial interest in high-resolution (5 meter or better) data. This dichotomy between the needs of science driven customers (i.e., NASA, NSF, and the Earth science community) and commercial customers has made the establishment of a LightSAR partnership particularly challenging. The current studies are focusing on this issue, to look for ways in which a mission capable of meeting science and commercial needs together can synergistically spawn new, cross-fertilized, science and commerce. Combined with a rapid response capability, a system of this dimension offers tremendous potential for numerous Earth science, commercial remote sensing, and operational applications. These include monitoring crops and natural vegetation, natural hazards, soil moisture, snow cover, land use, and the environment, as well as oil spill detection and measurement, topographic mapping, oil and mineral exploration, surveillance, and studying ocean waves and winds, and ice on seas, lakes and glaciers.

Section 2 of this report reviews the history of the LightSAR program, including the lessons-learned. Section 3 discusses the actions the agency can take to support an industry-led operational SAR capability in the United States, including discussion of a number of emerging mission concepts and collaboration approaches.

2.0 HISTORY AND BACKGROUND

2.1 LightSAR Workshop

The concept of a government-industry LightSAR mission was the focus of a workshop held at the Earth Resources Observation Systems (EROS) Data Center, Sioux Falls, South Dakota, in August 1996 [Ref. 1]. This workshop brought together over 150 of the nation's leaders in the imaging radar and remote sensing community. The workshop participants endorsed the concept of a government-industry partnership for a SAR mission, but declared that the 50%-50% industry-government cost share goal was unrealistic due to the market risk and uncertainty of customer demand for SAR data products. The participants recommended that the next steps should be to further study the market and technical risks before moving forward with a mission.

2.2 LightSAR Definition Studies

To address the concerns raised at the LightSAR Workshop, market analyses, mission concepts, technical approaches, and pilot applications projects were the subject of studies conducted by four competitively-selected industry teams in 1997 under Jet Propulsion Laboratory (JPL) "LightSAR System Design and Business Development Study" contracts. Members of the Definition Study teams are listed in Table 1.

A LightSAR Applications Workshop was held November 12-14, 1997 in Gulfport, Mississippi to summarize the non-proprietary conclusions from the industry Definition Studies and the results of commercial applications pilot projects. The teams concluded that the projected return on

Table 1. LightSAR Definition Study Teams

LEAD	*TEAM MEMBERS*
DBA	DBA Systems Inc., Orbital Sciences Corp. (formerly CTA Space Systems)
Vexcel	Vexcel, Ball Aerospace, South Dakota Space Technology Group, Earthwatch Inc., Spacetec; *Affiliates:* ERDAS, Univ. Michigan Radiation Lab (Prof. F. Ulaby), Bechtel, Dynamics Technology Inc. (DTI), Cargill, Georgia Pacific, CAL/FED
RDL	RDL, Spectrum Astro, ERIM, Harris, Alenia Spazio, Georgia Institute of Technology
Lockheed Martin Astronautics	Lockheed Martin Astronautics, Space Imaging EOSAT, Autometric, Earth Satellite Corp. (EarthSat), ERDAS, ERIM, Lockheed Martin Tactical Defense Systems, Observa, Inc., Pacific Meridian Resources, Univ. Michigan Radiation Lab (Prof. F. Ulaby), User Systems, Inc.

investment does not justify an industry investment in a science-focused mission (L-band-only), due to the limited market potential of a single-frequency system. To meet the needs of envisioned commercial applications, the teams recommended that a second frequency (X or C band) with high resolution capability be added to the L-band radar needed for science. However, they concluded that if industry must provide the additional investment needed when commercial requirements, such as the second frequency radar instrument, are added to NASA's science requirements, the market risk was too great to justify their required level of investment. Although the "optimistic" revenue projections for a dual frequency system with high resolution were substantial in the teams' market analyses, the return on investment analyses were tempered by the high uncertainty of the relatively immature commercial SAR market. The industry teams needed NASA to fund a significant portion of the commercial enhancements to the science capabilities in order to obtain an adequate commercial return on investment when the market uncertainties were taken into account. Thus, the industry teams endorsed moving forward with the mission and indicated that they would respond to a future partnership solicitation if NASA reduced the commercial risk by providing a sufficient government investment, particularly in the early years of the development phase.

Figure 1 illustrates the business risk of commercial investment in a SAR mission, showing the parametric sensitivity of the return on investment to the level of initial investment and revenue. The return on investment is represented by the Internal Rate of Return (IRR). The initial investment represents the pre-launch development investment, assumed to be spread over four years. The net revenue is the gross revenue less operating expenses, assumed to be spread over

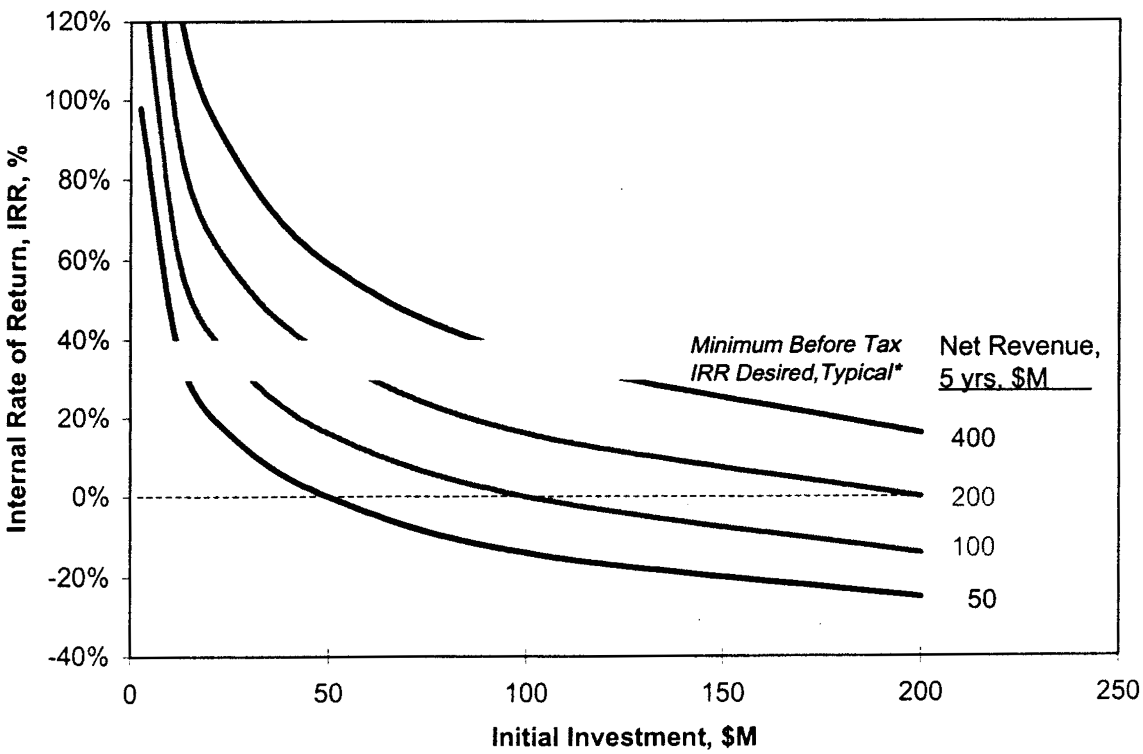

Figure 1. Business analysis - Return on investment sensitivity to initial investment and revenue.
**Based on LightSAR Industry Definition Study results.*

five years, with a 15% growth rate per year. The industry Definition Study teams each indicated that a projected 30 to 40% before-tax IRR is the minimum required to justify commercial investment. To achieve this return, Figure 1 indicates a roughly 4-to-1 ratio of revenue-to-investment is required. For example, a $100 million investment would require projected net revenues of about $400 million over five years to achieve a commercially viable financial return. Although the market analyses of the three Definition Study teams that considered a dual frequency, high-resolution system, did project potential revenues between $413 and $517 million over five years, the teams indicated that the market risk and uncertainty in the revenue projections was very high. In making future investment commitments, the Definition Study teams indicated that they would have to consider historical remote sensing satellite examples such as Radarsat 1, where the actual yearly revenue has typically turned out to be substantially less than the original projections. The Definition Study teams concluded that NASA dependence on substantial commercial investment in LightSAR is based on a questionable business case. However, they indicated interest in moving forward with a LightSAR mission based on a government-industry partnership if the NASA contribution was commensurate with the high market risk and uncertainty.

2.3 Science Background and Objectives

Prior to initiating the LightSAR project, NASA's Office of Earth Science (OES, formerly Office of Mission to Planet Earth) requested the Committee on Earth Studies (CES) of the Space Studies Board (SSB) of the National Research Council to provide a report on the scientific benefits of SAR. The CES produced a report that identified the value of SAR to provide improved understanding of earth, ocean, and atmospheric processes, and recognized the need for a U.S. civilian spaceborne SAR mission [Ref. 2]. NASA's OES also requested the Associate Administrator of NOAA for Satellite and Information Services to report on operational applications of SAR. In response, an Interagency Ad Hoc Working Group on SAR produced a report documenting the broad utility of SAR to support operational applications of a number of federal agencies [Ref. 3].

Upon initiating the LightSAR project, NASA commissioned a LightSAR Science Working Group (LSWG) in 1997 to define the LightSAR science objectives and requirements. The LSWG identified and recommended those key measurements, that can best be addressed through advanced active microwave remote sensing, that would provide the best scientific payoff relative to the goals of the NASA OES. The findings and recommendations of this multidisciplinary group are documented in Ref. 4. To provide a forum for the LightSAR industry study teams to interact with the LSWG, a LightSAR Science and Technology Workshop was held at JPL on May 1, 1997, to discuss the science requirements and develop ways to join science and commercial remote sensing interests.

As recommended by the LSWG, the highest priority science objectives, balancing scientific need and relevance against cost and complexity, are those that can be accomplished by repeat pass interferometry with an L-band (approximately 24 cm wavelength) SAR with a desired exact repeat time of 8-10 days. These objectives include seismic and volcanic deformation mapping, vector ice sheet and glacier velocity mapping, topographic mapping and surface characterization, and hazard monitoring and assessment. All these primary objectives are integral to the OES Solid Earth and Natural Hazard strategic plan, are unique, and have broad multidisciplinary community support.

SAR data provide unique information about Earth's surface and biodiversity, including critical data on natural hazards and data for use in resource assessments. SAR interferometric capabilities, which allow measurement of large-scale surface change at fine resolution, are required for monitoring surface topographic change and glacier ice velocity and, in many instances, for generating critical topographic data sets. Many recent literature citations have documented the contributions of interferometric radar to studies of earthquake mechanisms and propagation, volcanological hazard assessment, and refined measurements of the global ice-sheet mass balance.

The LSWG also concluded that for the LightSAR mission to provide data to scientists studying the Earth's carbon and hydrologic cycles, a polarimetric capability would be required. Specific objectives to be met here include monitoring forest regrowth, estimating soil moisture, and estimating snow density. Finally, a wide swath mode (250-500 km) would be required for oceanographic applications- they would also benefit from dual polarization capabilities.

Analysis of data from the SIR-C/X-SAR indicates that multiparameter (wavelength and polarization) SAR data can provide useful land cover classification and forest growth estimates; biomass estimation; mapping of wetlands; measurements of snow density, soil moisture, and surface roughness; characterization of oil slicks; and monitoring of sea ice thickness. Although the addition of a second frequency was not specified as a LightSAR science requirement, its addition as a commercial enhancement would certainly provide useful scientific benefits as well.

National Science Foundation (NSF) Advocacy for Interferometric SAR

More recently, and subsequent to the LightSAR Studies, the National Science Foundation (NSF) has been planning an interagency initiative known as EarthScope. EarthScope is a distributed, multi-purpose set of instruments and observatories that will expand the observational capabilities of the Earth Sciences and permit a great increase in understanding of the structure, evolution and dynamics of the North American continent. An EarthScope meeting was held at NSF on November 3, 1999. This meeting called together program officials from NSF, USGS, NASA, and DOE, and science leaders of the various sub-initiatives under EarthScope, to discuss interagency coordination of the EarthScope initiative. EarthScope seeks to link several observational facilities under consideration by the Earth Sciences Division at the NSF (NSF-EAR), the U.S. Geological Survey (USGS), and NASA into a single integrated effort.

One of the four major components of EarthScope is the Plate Boundary Observatory (PBO), which consists primarily of a geodetic array of permanent GPS stations and strain meters designed to cover the US plate boundary to map regional deformation fields in space and time. A complementary essential EarthScope component is a spaceborne interferometric SAR (InSAR) capability to map deformation over broad geographic areas. Existing and planned international SAR missions cannot deliver the required data.

NSF prepared a white paper (Appendix A) that summarizes the EarthScope initiative and endorses InSAR as an essential EarthScope component. NSF recognizes that NASA must play the key role in developing a mission to provide the InSAR observations the science community is calling for, and thus initiated the November 3 meeting to explore interagency collaboration.

NASA ESE Post-2002 Mission Studies

In 1998-1999 NASA consulted the Earth science community to identify a limited set of key measurements that best characterize the natural variability or forced changes of the total Earth system. The report of the Workshop on NASA Earth Science Post-2002 Missions [Ref. 5] concludes that, "a capability to carry out SAR interferometry belongs high on NASA's priority list for systematic measurement." The Solid Earth research and polar sciences communities gave highest scientific value to repeated (systematic) synthetic-aperture radar (SAR) surveys of land and ice surfaces, and tandem SAR missions, for differential interferometric reconstruction of surface topography and surface deformation over intervals of days (ice streams) to weeks (active tectonic regions).

The SAR technical requirements identified in these post-2002 mission studies are:

- High spatial resolution (of order 10-30m) SAR imaging system with multiple polarization capability
- Dual frequency (L-band + second frequency) or wide bandwidth (for split frequency analysis), optimized for repeat interferometric observations and minimal phase distortion by the ionosphere and atmosphere, and decorrelation by surface phenomena

In addition to the original LightSAR science requirements, NASA's Post-2002 Mission Studies identified Cold Land Processes as an essential Earth Science theme to be addressed by the post-2002 suite of NASA Earth Science missions. The goals of a SAR mission that addresses this theme are to: (1) measure the spatial and temporal dynamics of freeze/thaw and snow as a seasonal constraint on weather, carbon and hydrological processes, and human applications like trafficability; and (2) determine the interannual variabilities of freeze/thaw and snow, and how they affect and improve land-atmosphere feedback modeling, hydrology modeling, and high latitude carbon balance. The science data products that would be produced by a cold land processes SAR mission include: (1) maps of freeze and thaw dates by monitoring temporal shift in radar backscatter relative to winter frozen conditions due to dielectric shift with freezing; and (2) snow water equivalent evaluation by producing maps of snow depth and density based on polarimetric radar scattering differences. A dual frequency (L and X-band) polarimetric SAR with adequate repeat coverage would be an invaluable tool to support cold land processes objectives.

SAR Ice Mapping Applications

Reference 3 describes operational applications of SAR by other governmental agencies. The National Oceanic and Atmospheric Administration (NOAA) and U.S. Coast Guard (USCG) have provided additional information on the need for spaceborne L and X-band SAR measurements to support Great Lakes and sea ice mapping applications, in Appendixes B and C.

2.4 Technology Development

A number of technology risk mitigation activities were initiated to address the L-band radar technology risk issues raised by industry at the 1996 LightSAR Workshop. These activities include the NASA Advanced Radar Technology Program (ARTP) and the formation of a Payload Technology Alliance consisting of the four original LightSAR Definition Study teams augmented with leading industry radar instrument technology providers. See Table 2. The ARTP focused its efforts on the development of technology for the radar system Radio Frequency (RF) electronics and Digital Electronics. The LightSAR Payload Technology Alliance addressed critical L-band technologies for LightSAR, primarily in the challenging antenna design.

Table 2. Technology provider members of the LightSAR Payload Technology Alliance

Alliance Member	**Technology**
Lockheed Martin Communications & Power Center	Lightweight phased array antenna
Ball Telecommunications Products Division	" " " "
Composite Optics , Inc.	Structurally enhanced antenna panel planar array
Lockheed Martin Communications & Power Center	Deployment / support structure
AEC-Able Engineering	" " "
Astro Aerospace Corporation	" " "
ITT Gilfillan Defense Electronics	L-band Transmit/Receive (T/R) modules
Sanders, A Lockheed Martin Company	" " " "
JPL	Lightweight prototype RF / Digital subsystem
JPL / Composite Optics	Lightweight L-band antenna panel
JPL / University of Massachusetts	Dual-band shared aperture radar

The prototype RF and Digital Electronics developed by these programs, including an 80MHz microstrip patch antenna fabricated to the same design as proposed for the LightSAR antenna panels was flown and tested as part of a 1998 upgrade to the NASA/JPL AIRSAR system. End-to-end system tests conducted during a series of AIRSAR flights verified the LightSAR L-band design concept by producing exceptional quality, first-ever, 3 m resolution L-band SAR images.

The ARTP and LightSAR Payload Technology Alliance enabled LightSAR to leverage the best technologies available in government and industry, and technology developments and risk mitigation by these efforts have significantly advanced the maturity level of critical technologies to the point where they no longer present significant risk.

Technology developments in addition to the above that could be considered for NASA's next SAR mission include the emergence of an innovative electrically scanned reflector antenna concept being developed by Ball Aerospace that has the potential for substantial mass reduction and performance enhancement. Also, a potential breakthrough in science-commercial coexistence is the dual frequency radar instrument concept under study at JPL, which provides independent, simultaneous, operation of both radar frequencies. This capability is expected to greatly reduce potential for science and commercial tasking conflicts. The dual frequency mission concept described in Section 3 utilizes this unique capability. Technology issues related to dual frequency radar operation are presently under study.

2.5 EOCAP-SAR

The NASA Stennis Space Center Commercial Remote Sensing Program (CRSP) Office initiated an Earth Observation Commercial Applications Program for Synthetic Aperture Radar (EOCAP-SAR) in 1998. The objectives of the EOCAP-SAR program are to promote market development for new and innovative imaging radar data products and services in general, and to develop potential LightSAR markets in particular.

The intent of the EOCAP-SAR was to extend and enhance the pilot applications projects that were initiated during the LightSAR Definition Studies and open new opportunities to address SAR markets with special consideration of data from a potential future LightSAR system. EOCAP-SAR established partnerships between government and twelve industry teams involving business and technical assistance and the sharing of costs and risks. The team leaders are Boeing, Northwest Research Associates, Research and Development Laboratories, Technology Service Corporation, Ocean Imaging, Information Integration & Imaging, Vexcel, Earth Information Systems Corporation, Shell, ERIM International, Inc., EnviSense, and Eastman Kodak Company. An EOCAP-SAR Phase I Workshop was held at Stennis Space Center in September 1999 to report progress by the program participants.

The EOCAP-SAR encourages an innovative partnership approach to designing, developing, and managing market-driven SAR products and services and begins the process of moving SAR and related space technologies to the commercial market. It further encourages the development and demonstration of SAR data applications and technical-business innovation to expand and diversify the economic uses of SAR data products. It also plans to expand public as well as private understanding of the limitations and unique capabilities of current SAR data sources and services, to identify technology deficiencies or gaps, and to help establish the performance and cost requirements for future systems and services.

2.6 LightSAR Announcement of Opportunity

The results of the industry definition studies led NASA to release an Announcement of Opportunity (AO) in March 1999 for an industry partner to conduct the LightSAR mission (AO-

99-OES-01, Ref. 6). In the AO, the industry partner was responsible to design, build, launch, and operate the LightSAR system; process, distribute, and sell the acquired image data and related products; and conduct unique scientific investigations. The intent was for the Industry Partner, in return for exclusive commercial rights to the LightSAR data beyond NASA's science data, to share with NASA the costs, risks and benefits of the venture.

The results of the AO process were disappointing. Although the LightSAR AO allowed industry to propose any government-industry cost share percentages that they could justify, the high SAR market risk and uncertainty led to the submission of only a single industry proposal. That proposal was from a team that included the merging of two members of the original four LightSAR Definition Study teams. The proposal was evaluated in accordance with the procedures stated in NASA FAR Supplement (NFS) 1872.4. After thorough evaluation and careful deliberation, NASA decided not to select the proposal for award. Although the proposal did offer a significant industry cost contribution, it contained a number of weaknesses in several areas, and it was rejected primarily for the reason that it was based on a fragile business plan that posed an unacceptable financial risk to the government.

2.7 International SAR Developments

A number of foreign SAR missions are in development or are being planned. Each of these systems has a wide range of capable SAR modes, including polarimetry, repeat-pass interferometry, and wide-swath ScanSAR coverage. Each of the sponsoring space-agencies hopes to encourage commercialization of the data, through value-added development and in some cases explicit sales of the data.

Radarsat, Canada's first spaceborne SAR system, was the world's first explicitly commercial SAR mission. Radarsat was funded with Canadian government funds except for the launch vehicle, which was provided by NASA in exchange for access to data for NASA scientists. Radarsat International (RSI) was given rights to market the data from Radarsat. The system operates at C-band, and has numerous fine-beam and ScanSAR modes. Because the data are not high resolution, the Radarsat commercial experiment has been considered only moderately successful, in that the volume of data sales could not hope to generate enough revenue to compensate a company for the entire mission development cost. Canada is planning a follow-on mission, Radarsat II, which will be much more capable. It will again be a C-band system, with the spacecraft bus provided by Alenia Aerospazio of Italy, and will have polarimetric and ScanSAR capabilities in addition to fine resolution to enhance the commercial viability of the mission. Nonetheless, the Canadian government needs to provide the majority of the mission development funding.

Envisat, the European Space Agency's follow-on to the successful ERS satellites, is a C-band sensor scheduled to launch in 2002. Envisat is primarily a science mission, but ESA continues to pursue commercialization of data as aggressively as it did for ERS. In Europe, companies have derived substantial revenue from value-added products from ERS. ESA expects this trend to increase with the multi-year time-series, polarimetric capabilities, and ScanSAR.

ALOS, the next Japanese SAR and the follow-on to the successful JERS-1, will be an L-band fully polarimetric multi-mode sensor. It is presently scheduled to launch in 2003. The Japanese Space Agency (NASDA) does not have explicit plans for commercialization of their data. In fact, NASDA is seeking partnerships with other governments, including the U.S., to help them to archive, process, and disseminate their data. Their international data node concept is quite novel, and is restricted to non-commercial uses. NASDA and the Japanese government has not formulated a position with respect to commercialization of their data yet, but clearly commercial potential exists in the moderate resolution value-added markets similar to those developing in Europe for ERS and Envisat data.

On the drawing boards are international plans farther into the future. Germany and Great Britain are pursuing a multi-frequency, multi-polarization platform called TerraSAR that is in direct competition with many of the LightSAR capabilities and commercial objectives. France is studying a satellite constellation flying in formation with ALOS that would enhance the topographic mapping capabilities to be similar to the U.S. SRTM mission, but in a continuous free-flying configuration, providing better quality data, and global coverage because of the orbit configuration. . Italy is studying a constellation of SAR and optical satellites called SkyMed/COSMO. This system will be dedicated to Earth resource mapping and commercial applications in the Mediterranean basin.

The international SAR arena is dynamically alive, and moving rapidly toward commercialization of global data sets with a variety of resolutions and characteristics. Other governments are not waiting for the "economics to be right" to engage industry in development of their commercial markets. They recognize that the government must provide the majority of SAR mission funding and that they need to promote the value-added sector in order to foster the up front market development needed to make future commercial missions possible. Rapid development of a unique U.S. SAR program is essential to be competitive in this environment.

While these international missions will likely produce exciting science results, none is tailored to deliver the breakthrough science that is expected in the U.S. post-2002 Earth science mission plan. This is so for many reasons. Only one of these international sensors, ALOS, operates at L-band. Experience with C-band instruments shows that a large portion of science target areas covered in vegetation will not be stable for interferometric observations at C-band. Even so, the repeat interval of the ALOS orbit is too large to support the time-series analysis required for long-term deformation studies, or any of the fast deformation signatures like ice stream or glacier flow. Furthermore, as a foreign asset, it is not clear how much influence the U.S. science community can have in tasking ALOS, or any other international sensor, to obtain the needed science data. Finally, the data volume required to support NASA science needs is many times greater than can be expected to be delivered by ALOS. Given these uncertainties and limitations, a U.S. mission that produces the required science data is needed.

Foreign nations clearly recognize the advantages to their commercial and scientific interests by building and flying SAR satellites. These nations' information technology industries and scientists will continue to take advantage of the data provided by their SAR missions. The

United States is uniquely positioned to provide commercial information technology industries and scientists with a national capability that exceeds the capabilities currently planned for foreign missions. NASA's SAR technology enables the United States to put a dual frequency radar with the resolution and operating parameters needed by commercial and scientific interests on-orbit before any foreign mission is launched with similar capabilities. If NASA moves forward with such a mission, U.S. commercial interests will be the first to market with new products and scientists will benefit from an advanced tool (unavailable anywhere else) for performing research into Earth processes.

2.8 Summary of Lessons-Learned from LightSAR

After reviewing the history of the LightSAR project, the following is a summary of the lessons-learned:

- The SAR commercial market risk and return on investment do not justify an industry investment in a science-focused mission (L-band only). Thus, there was no proposal submitted to the LightSAR AO for a system that focused primarily on meeting the NASA science requirements.
- Furthermore, the market risk and uncertain return on investment do not justify the large industry investment needed when commercial requirements are added to NASA's science requirements. Without substantial up-front data buy commitments from a number of customers, the immature SAR market results in very high uncertainty in projected returns on investment. This makes it difficult for industry to secure confirmed financial investment commitments. Resulting business plans are fragile, resulting in an unacceptably high financial risk to the Government. If the business fails, then the risk of NASA loosing its own substantial investment is unacceptable, and the opportunity for obtaining critical science data for the Earth sciences community would also be lost for a number of years. Figure 1 gives an indication of the fragile business case for commercial investment in a SAR mission.
- Technology developments and risk mitigation by the LightSAR project and related efforts have significantly advanced the maturity level of critical technologies to the point where they no longer present significant risk. The technology is ready and the capability exists for the U.S. to develop the world's preeminent SAR mission.
- With the identification of key SAR measurements needed in NASA Earth Science Post-2002 Missions, and the NSF identification of an InSAR mission as an essential element of their EarthScope initiative, the science community's need for SAR data is now even greater and broader than during the LightSAR program.
- The scientific, commercial, and technology objectives of LightSAR remain valid and important, and can be achieved if a new approach is developed that reduces the financial risk to both government and industry, and meets a wide range of science and commercial needs.

The following section describes actions the agency can take to create an operational SAR capability in the United States.

3.0 ACTION PLAN

3.1 Introduction

Based on the lessons-learned from the LightSAR program, there is a need for a new approach that substantially reduces financial risk, boosts commercial potential, and fosters a resource-sharing partnership that mutually benefits both the government and industry. At the same time, there is a growing urgency to move forward with a SAR mission to meet critical Earth science needs, affirm U.S. leadership in SAR science, technology, and commercial remote sensing, and advance U.S. commercial competitiveness ahead of foreign SAR missions being planned and developed.

There are a number of actions the agency can undertake to support industry-led efforts to develop an operational synthetic aperture radar capability in the United States. NASA plans to continue studying different mission concepts, collaborations, and implementation approaches as part of their technology infusion program, and to continue preservation of the technology required to field a world class system which will assure the United States leadership position in radar remote sensing. These studies will include exploration of resource-sharing arrangements with the private sector and encourage commercialization of the system to the largest extent possible.

NASA intends for its plans for a SAR mission to be given the widest dissemination possible. NASA wants to provide users of SAR remote sensing data and information the opportunity to influence the system capabilities, technical parameters, and mission design so that it meets the needs of a broad base of potential users. To promote this dialogue, user workshops were conducted in December 1999 and January 2000. NASA also wants to provide industry with the opportunity to provide feedback on partnership and implementation approaches, and plans to hold a future workshop to encourage this dialogue.

3.2 SAR User's Perspective

To understand the imaging radar users' perspective, NASA/JPL conducted a Petroleum Industry SAR User's Workshop in Houston on December 2, 1999. A subsequent workshop for the broader remote sensing data and information user community was held in conjunction with Texaco on January 19-20, 2000. This workshop included representation from the petroleum, agriculture, forestry, remote sensing, value-added services, and Aerospace industries, as well as government agencies. The workshop proceedings are available at: http://southport.jpl.nasa.gov/SAR_Users_Workshop/. The consensus at these workshops was that the participants supported the dual-frequency, high-resolution, polarimetric, interferometric, SAR concept described below in Section 3.3.2, and supported the need for this nation to move forward now with development of such a mission. Furthermore, a SAR Information Users Working Group is now being formed to foster advocacy of this mission, enable users to influence the system capabilities and design, and to continue government-private sector dialogue on how to proceed. This Working Group can also help to address issues such as data rights, data policy, mission planning and conflict resolution with the project team, including a future commercial partner, if appropriate.

Based on a synthesis of the results of these workshops, as well as the LightSAR Definition Study results, a set of basic system capabilities needed to meet science and broad commercial needs has emerged. The dual frequency, high-resolution, polarimetric, interferometric SAR concept described below in Section 3.3.2 is capable of addressing post-2002 NASA ESE SAR measurement objectives (including the LightSAR science objectives), the NSF/EarthScope InSAR science objectives, rapid environmental emergency response operational objectives, plus a broad range of other applications such as environmental management, mapping, surveillance, forestry, agriculture, and land use and urban planning. Appendix D includes letters of support for this mission concept from a number of other government agencies and organizations. Appendix D also includes letters of endorsement from Texaco and the California Independent Petroleum Association supporting the concept of collaboration between NASA and the OSLTF to co-fund this mission.

3.3 Emerging Concepts and Approaches

A number of mission concepts, and collaboration and partnership approaches are under study. The three concepts presented in this section are representative of the range of options being considered, each addressing a different balance of science and commercial interests.

3.3.1 Focused Science (InSAR) Mission

As described in Section 2, the recent NSF endorsement of InSAR as an essential component of the EarthScope initiative suggests that one option that should be considered by NASA is a science-focused InSAR mission. The dual frequency mission concept described in the following section certainly has broader utility in terms of meeting EarthScope InSAR and a wide range of other science and commercial objectives. However, a substantially less expensive, single frequency (L-band), moderate resolution system focused on InSAR could address the EarthScope objectives.

Variations of an InSAR mission can also be studied. For example, adding an L-band polarimetric capability and a wide swath ScanSAR mode would enable the system to increase its science (and possibly commercial) utility beyond EarthScope InSAR, addressing a broader scope of the NASA ESE post-2002 measurements, at some additional cost. The cost of a focused InSAR science mission with these kinds of enhancements is estimated to be about $200 million. Cost-sharing between NASA and NSF could lead to a sensibly modest business investment toward building the markets and infrastructure for future more heavily commercial SAR missions.

A focused InSAR science mission could create opportunities for commercialization through value-added products and services, including data distribution rights, ground stations, low-cost receiving terminals, and processing. Such concepts have already been explored in recent years in the context of science mission proposals to NASA. One option to be considered is contracting with industry to operate the satellite, and offering them commercial data rights. However, the commercial utility and cost share potential of such a system is admittedly limited without high resolution, polarimetry, and a second frequency.

Overall, a focused science mission approach offers important Earth science benefits and should be seriously considered if the dual frequency concept described in the following section becomes unaffordable. At the same time, if industry proposes to move forward with a fully financed commercial SAR mission, it could focus on the more lucrative mapping and surveillance markets, with the Department of Defense as a potential significant customer. Such a system could consist of a single frequency high resolution SAR instrument (e.g. X-band), which would be more commercially affordable than a dual frequency system designed to also meet NASA science needs. Research and Development Laboratories (RDL), one of the original LightSAR study team leads, has been attempting to secure financing for such a system for a number of years, although unsuccessfully so far. A focused L-band InSAR science mission developed separately by NASA could then complement a separate commercial system without competing with it.

3.3.2 Dual Frequency Dual Use SAR Mission

Based on the results of the LightSAR Definition Studies and the recent SAR Users Workshops, it is clear that to meet the broadest range of science and commercial objectives, a SAR mission needs to contain a dual frequency, polarimetric SAR instrument with high resolution (5 m or better) capability. Adding a second frequency and high resolution greatly increases both the science and commercial utility of the mission, but the costs of such a mission are substantially greater than for a single-frequency, moderate-resolution, focused-science mission. To enhance the affordability of such a mission, cost sharing partnerships need to be explored. However, one clear lesson learned from the LightSAR experience is that the SAR commercial market risk is very high and the level of potential investment by the private sector is highly uncertain.

One approach to "buy-down" the financial risk to both the government and industry is to increase the level of government investment. The capability to support rapid response to oil spill emergencies and environmental preservation has led to the suggestion that NASA explore collaboration with the Oil Spill Liability Trust Fund (OSLTF) to provide the government funding for this option. The OSLTF was established as a result of the Oil Pollution Act of 1990 (OPA 90).

In September 1999, Dr. Alfredo Prelat, Texaco Fellow and ALTO Technology Resources President, initiated discussions with NASA and expressed strong Texaco support for a NASA / OSLTF collaboration to develop a SAR mission, under the condition that the petroleum industry participate in the selection of the system parameters, and that they receive priority tasking for oil spill emergency response. NASA considers these conditions to be reasonable and appropriate. After meetings and discussions between NASA/JPL and Dr. Prelat and his staff, a preliminary mission concept has emerged. With global visibility, all-weather, day-night imaging with a dual frequency, high-resolution, polarimetric, interferometric SAR instrument, this mission is capable of addressing the basic requirements for rapid oil spill response and environmental management, as well as the remote sensing resource exploration needs of the petroleum industry. It also addresses the science objectives defined for LightSAR, NSF/EarthScope InSAR, and Cold Land Processes Research, as well as a broad range of potentially lucrative commercial applications.

In addition, a potentially breakthrough feature incorporated in the system is that the two radar frequencies can operate independently. When combined with electronic steering capability, the potential for conflicts between science and commercial tasking is greatly reduced, as the primary science interest is in the L-band and the primary commercial interest is in X or C-band data. This capability helps to address a major concern expressed by both industry and the science community during the LightSAR studies – that the conflicting needs of a dual-use mission may interfere with science return and commercial interests.

The collaboration and mission concept, and the results of the Petroleum Industry SAR Users Workshop were reported to the U.S. Coast Guard. The mission concept addresses 7 of the 10 "Priority 1" objectives outlined by the Coast Guard in their Oil Pollution Response Plan that was produced in response to the OPA 90 [Ref. 7]. In addition to oil spill response, the proposed mission can provide important complementary capabilities that support a number of other important Coast Guard needs in the areas of Marine Safety and Environmental Protection, and Law Enforcement. For example, Ref. 2 identified maritime drug interdiction, detection and interdiction of illegal transport and landing of weapons and counterfeit consumer commodities as applications that can benefit from the use of SAR-derived observations of ships and ship wakes, particularly under cloud cover and at nighttime. Appendixes B and C describe applications of L and X-Band SARs to Great Lakes ice cover mapping and sea ice remote sensing in polar regions, that are of both scientific and operational interest to the Coast Guard as well as NOAA.

SAR is used operationally by a number of nations (e.g., Norway, Brazil) for responding to oil spills, primarily using Radarsat 1 or ERS data. The greatest obstacle to routine operational use of spaceborne SAR systems for oil spill response has been the difficulty of obtaining rapid response. The dual frequency NASA SAR mission and operations concept described here is being designed from the outset to provide rapid global response, particularly for U.S. coastal regions and the Gulf of Mexico. The ground segment concept includes a primary ground command/control and receiving station, as well as a long term data archive, located in Sioux Falls, South Dakota and a northern latitude ground station located in Fairbanks, Alaska. This enables coverage of the U.S. Coast and Gulf of Mexico so that data can be acquired by the satellite and downlinked simultaneously. The data can then be rapidly transferred through commercial communications links to a proposed Environmental Response Data Center located in Houston, Texas. Rapid response processing at this data center enables information to be delivered to oil spill response teams in time to influence decision making to support spill mitigation. Global orbit coverage analysis shows that sites can be accessed within 11 hours, on average. There is a 95% probability of access within 24 hours. Utilization of foreign SAR satellites in conjunction with NASA's SAR satellite would further improve access time. Also, remote sensing centers at Mississippi Universities could participate by the addition of a low cost receiving station that would provide student and faculty access to SAR data to support Gulf region applications.

Scientists also have great interest in rapid response to natural disasters. In that case, scientists favor the distributed downlink approach used successfully in weather-related disaster monitoring. Commercial operations could also potentially benefit from distribution of the downlink.

A partnership approach being considered for this mission option focuses the government-industry collaboration in the ground segment and operations. It is this segment of the mission that has the greatest potential for generating revenue and promoting market growth and business expansion. A competitively selected industry team would be responsible for leading the ground segment development and operations. This includes spacecraft command/control, data downlink, acquiring, processing, distributing and archiving the data, and customer services. Resource sharing would be encouraged in return for commercial data rights. With a lower commercial investment requirement, this approach lowers the risk of obtaining an adequate return on investment. This approach would provide industry with an affordable commercial pathfinder mission that is funded primarily by the government. It would enable industry to test the market projections alluded to in Section 2.2, foster market expansion, and create the infrastructure needed to enable a future commercial SAR mission. Relative to the LightSAR approach, it is a smaller, more realistic, step towards a future fully commercially funded follow-on SAR mission, with NASA participation as a data customer.

One way to implement this partnership approach is an initial phase where two teams would be competitively selected to work independently for a short period (e.g., 4-6 months), culminating in a system requirements review. This initial phase would allow the teams to influence the flight system requirements and design early on so that desired commercial capabilities are adequately considered, and would provide them time to finalize their business plans and secure financial resource-sharing commitments. Determination of the most effect partnering arrangement and down-selection of a single mission partner would then follow.

In this proposed partnership approach, the government would be responsible for developing and launching the flight segment, including the spacecraft and SAR instrument. Key flight segment elements, such as the spacecraft bus and radar antenna, would be obtained through competitively awarded subcontracts to industry. Having the government responsible for the flight segment leverages the substantial NASA experience and investment in SAR mission development, and utilizes the best capabilities of U.S. industry, and thus is expected to reduce the overall risk to both NASA and industry.

If the government were prepared to fund this mission, e.g. through co-funding from NASA and the OSLTF, the mission viability would not depend on highly uncertain assumptions and projections about the level of commercial investment. Industry would be encouraged to contribute resource sharing in their ground segment/operations proposal. The resulting cost reduction to the government would be an important consideration in the proposal and subsequent down-selection evaluation process, and competitive market forces will drive the ultimate level of industry investment. Any reduction in government cost would be passed on to NASA and the OSLTF collaborative partners. This approach greatly improves the projected return on industry investment, reduces the commercial risk substantially, and enhances the commercial viability. With lower commercial risk, the overall financial risk to the government is also reduced.

The life cycle cost of this mission is estimated to be about $400 million, including five years of operations. The detailed development schedule developed for this mission indicates that it can be launched within four years after project start.

In summary, this dual-frequency SAR mission concept and approach enables achievement of ambitious science, technology, commercial remote sensing, and environmental preservation objectives. The private sector plays a large leadership role in this mission concept, as the petroleum industry and a SAR Information User Working Group participates in the selection of the system technical parameters, and a commercial partner leads the ground segment development and operations.

The dual frequency mission concept was presented at the January 19-20 SAR Users Workshop. Additional detail and preliminary plans for implementing this concept are available in the workshop proceedings [Ref. 8].

3.3.3 Commercial SAR Mission

The SAR market analyses and revenue projections developed by industry as part of the LightSAR Definition Studies concluded that the SAR market is too immature to provide an adequate return on investment to justify even a 50%-50% government-industry cost share arrangement. In recognition of this, the LightSAR AO allowed industry to propose any government-industry cost share percentages that they could justify. Even so, the high SAR market risk and uncertainty led to the submission of only a single industry proposal. That proposal did offer a significant industry cost contribution. However, as described in Section 2, it contained a number of weaknesses in several areas and was rejected primarily for the reason that it was based on a fragile business plan that posed an unacceptable financial risk to the government.

At this time there is no reliable evidence that the private sector can realistically fund the development of a SAR mission. Figure 1 indicates the revenue required to justify a fully-commercially funded SAR mission is not viable at this time. Development costs for a SAR mission range between below $200 million (for a single frequency system) to $350 million (for a multiple operating mode, dual frequency, system). To obtain a 30%-40% internal rate of return (IRR) for a $200 million system would require about $800 million in net revenue over 5 years! Securing guaranteed data buys for anything close to this value from government agencies and other sources is unrealistic at this time. The business case clearly gets even worse for a more expensive dual frequency system.

If the above situation changes and the private sector were to move forward and credibly demonstrate their ability to finance and develop a commercially-funded SAR mission, NASA would certainly consider purchasing data if it meets NASA's science needs. However, if NASA waits and depends on the private sector to develop such a mission, there is a very high risk of losing the opportunity for obtaining critical earth science data, including InSAR data urgently needed by the EarthScope initiative, in the near future. If NASA instead steps up to take a leadership role in developing a SAR mission, and fosters growth of the commercial market and value-added capabilities, it would help make it possible for U.S. industry to consider funding a follow-on SAR mission in the future, with NASA as a data customer.

3.3.4 Other Collaboration Possibilities

There is precedent for international collaboration on U.S.-led SAR missions, including SIR-C/X-SAR, SRTM, and the 1998 ECHO-ELSIE Earth System Science Pathfinder (ESSP) proposal submitted jointly by U.S. partners and CNES.

The Italian Space Agency, ASI, has expressed interest in collaboration on NASA's next SAR mission through the potential contribution of an X-band radar instrument, in a November 1, 1999 letter from ASI President Sergio De Julio to Dr. Charles Elachi, JPL Director of Space and Earth Sciences Programs. This collaboration option is presently being explored. Issues that need to be addressed include ensuring that the ASI radar is capable of meeting the identified user needs for the X-band instrument, and the parameters of a data rights agreement that would be acceptable to all stakeholders, including ASI, NASA and a potential commercial mission partner.

Other nations, such as Canada, Germany, and Japan are presently planning and developing SAR missions. Mission collaborations with some of these nations were explored for LightSAR, with varying levels of interest. With the dynamic domestic and foreign funding environment, collaboration possibilities can be explored again for a new SAR mission. Particular areas for exploring collaboration possibilities include science data exchange and response to natural disasters and environmental hazards (e.g., oil spill response).

Collaborations with the Department of Defense (DOD) have been explored in the past during the LightSAR program, but no serious collaboration interest materialized. It was difficult to find strong synergy between the proposed DOD SAR mission objectives and the science and commercial objectives of LightSAR. However, as the funding environment evolves for DOD SAR missions that were in the planning stages, new collaboration possibilities can be explored.

Collaboration with NSF for elements of the ground segment and operations, including science data processing, will also be explored.

3.4 Recommendations

NASA plans to continue studying different mission concepts, collaborations, and implementation approaches, including those described above. Cost-share collaboration with the OSLTF is a particularly promising approach that could enable NASA to develop a dual use, dual frequency, high-resolution, interferometric, polarimetric SAR mission that would address science, environmental management (e.g., oil spill response), and commercial applications with a globally preeminent imaging radar mission.

One government-industry partnership approach that will be explored further is having industry lead the ground segment development and operations, with resource sharing encouraged in return for commercial data rights. NASA and the OSLTF participants would be considered data customers, with data provided by the commercial partner in return for the NASA/OSLTF initial investment. The petroleum industry and the SAR Information users Working Group also participates in the selection of system technical parameters. This approach is expected to foster growth in commercial remote sensing and has the potential to lead to a future commercially financed and developed SAR mission, with NASA as a data customer. The participants of the January 2000 SAR Users' Workshop supported the dual frequency mission concept and collaboration approach, and recommended that this nation move forward now with mission development.

If full government funding for this mission is not made available, for example through the OSLTF collaboration or an alternate significant cost share partnership, a less expensive science-focused mission should be considered that would address the Earth Science community's post-2002 SAR measurement needs and NSF's EarthScope / InSAR initiative.

NASA also plans to continue preservation of the technology required to field a world class system which will assure the United States leadership position in radar remote sensing. NASA will continue to explore resource-sharing arrangements with the private sector and encourage commercialization of the system. NASA will also explore other government agency and international collaborations. NASA also intends to facilitate future SAR Information Users Working Group meetings to continue government-private sector dialogue on how to proceed.

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5.0 APPENDIXES

A. National Science Foundation (NSF) EarthScope White Paper

EarthScope – A Look into Our Continent

EarthScope is a distributed, multi-purpose set of instruments and observatories that will expand the observational capabilities of the Earth Sciences and permit us to greatly increase our understanding of the structure, evolution and dynamics of the North American continent. Advances in theory, computing, and the technology of optical and radio telescopes have allowed us to look upward, ever deeper into the universe. Similarly, theoretical, computational, and technological advances in seismology, satellite geodesy, and drilling and downhole instrumentation provide the tools to make major advances in looking downward into the planet. New broadband and portable seismometers deployed in large arrays can provide high resolution images of crust and mantle structure, as well as details of the earthquake rupture process. High-precision geodesy using GPS can map regional deformation fields in space and time. InSAR represents a complementary means of mapping deformation over broad areas with high spatial coherence. Advances in drilling, sampling, and downhole measurement technology made by the petroleum industry bring new scientific targets, previously unattainable, within our reach. For example, scientific drilling deep into the San Andreas fault will, for the first time, enable direct measurement of the physical conditions under which plate boundary earthquakes occur. Strainmeters deployed both at the surface and at depth along active fault zones, give us nano-strain sensitivity with the ability to measure deformation transients that provide new insight into the processes of crustal loading, aseismic slip, and earthquake nucleation. Complementary technological advances are taking place in microelectronics, data collection systems, and communication, allowing miniaturization of instrumentation and efficient real-time handling of vast volumes of data from large arrays of geophysical instruments.

EarthScope embraces these developments and seeks to link several observational facilities under consideration by the Earth Sciences Division at the National Science Foundation (NSF-EAR), the U.S. Geological Survey, and NASA into a single integrated effort. These observational facilities provide a framework for broad, integrated studies across the Earth Sciences, including research on earthquakes and seismic hazards, magmatic systems and volcanic hazards, lithospheric dynamics, regional tectonics, continental structure and evolution, and fluids in the crust. EarthScope is being proposed through the NSF Major Research Equipment (MRE) Program, and will consist of the following components: a) a continental scale array of broad-band and short-period seismometers to provide a coherent 3-D image of the lithosphere and deeper Earth (**USArray**), b) fixed arrays of strainmeters and Global Positioning System (GPS) receivers to measure real-time deformation on a plate boundary scale, (Plate Boundary Observatory – **PBO**), c) a deep borehole observatory along the San Andreas fault to directly measure the physical conditions under which earthquakes occur (San Andreas Fault Observatory at Depth – **SAFOD**), and d) satellite-generated Interferometric Synthetic Aperture Radar images of tectonically active regions of the continent (**InSAR**).

USArray will dramatically improve the resolution of seismic images of the continental lithosphere and deeper mantle, and integrate these images with a diversity of geological data to address significant unresolved issues of continental structure, evolution, and dynamics. A hierarchical design achieves imaging capabilities that span the continuous range of scales from global, through lithospheric and crustal, to local. The core of USArray is a transportable telemetered array of 400 broadband seismometers designed to provide real-time data from a regular grid with dense and uniform station spacing of ~50 km and an aperture of ~1000 km. The array will record local, regional, and teleseismic earthquakes, producing significant new insights into the earthquake process, and providing resolution of crustal and upper mantle structure on the order of tens of kilometers and increasing the resolution of structures in the lower mantle and at the core-mantle boundary. The transportable array will roll across the country with 1-2 year deployments at each site. Multiple deployments will cover the entire continental U.S. over a period of 8-10 years. When completed, this will provide unprecedented coverage for 3-D imaging from ~2000 seismograph stations. While the initial focus of USArray is coverage within the United States, extensions of the array into neighboring countries and onto the continental margins in collaboration with scientists from Canada, Mexico and the ocean science community would be natural additions to the initiative.

An important second element of USArray is a pool of ~2400 portable instruments (a mix of broadband, short period, and high frequency sensors) that can be deployed using flexible source-receiver geometries. These instruments will allow for high-density, shorter-term observations, using both natural and explosive sources, of key targets within the footprint of the larger transportable array. Many important geologic targets are amenable to investigation with the flexible array including: the depth extent of faults, magma chamber dimensions beneath active volcanoes, the relation between crustal tectonic provinces and mantle structure, the shape of terrane boundaries, the deep structure of sedimentary basins and mountain belts, and the structure and magmatic plumbing of continental rifts. Linked with coordinated geological, geochemical, and geodetic studies, this component of USArray can address a wide range of problems in continental geodynamics, tectonics, and earthquake processes. Examples include imaging the continental arc system in the Cascades from slab to edifice, examining the deep roots of the North American craton and paleotectonics by which the craton was formed, imaging both ancient and modern orogens and rifts to explore variability in continental tectonics, identifying the role of the mantle lithosphere during orogenesis and rifting, and unraveling the relationship between deep processes and surface features.

A third element of USArray is an augmentation of the National Seismic Network, operated by the U.S. Geological Survey. Relatively dense, high-quality observations from a continental network with uniform spacing of 300-350 km is important for tomographic imaging of deep Earth structure, providing a platform for continuous long-term observations, and establishing fixed reference points for calibration of the transportable array. This component of USArray will be coordinated with the USGS and complements the initiative underway at the USGS to install an Advanced National Seismic System (ANSS).

SAFOD is designed to directly sample fault zone materials (rock and fluids), measure a wide variety of fault zone properties, and monitor a creeping and seismically active fault zone at depth. A 4-km-deep hole will be drilled through the San Andreas fault zone close to the hypocenter of the 1966 M~6 Parkfield earthquake, where the San Andreas fault slips through a combination of small-to-moderate magnitude earthquakes and aseismic creep. The drill site will be located sufficiently far from the San Andreas fault (as determined by geologic observations, microearthquake locations, and geophysical imaging) to allow for drilling and coring deviated holes through the fault zone starting at a vertical depth of about 3 km and continuing through the fault zone until relatively undisturbed country rock is reached on the other side.

Even after decades of intensive research, numerous fundamental questions about the physical and chemical processes acting within the San Andreas and other major plate-bounding faults remain unanswered. SAFOD will provide new insights into the composition and physical properties of fault zone materials at depth, and the constitutive laws governing fault behavior. It also will provide direct knowledge of the stress conditions under which earthquakes initiate and propagate. Although it is often proposed that high pore fluid pressure exists within the San Andreas fault zone at depth and that variations in pore pressure strongly affect fault behavior, these hypotheses are unproven and the origin of overpressured fluids, if they exist, is unknown. As a result, a myriad of untested and unconstrained laboratory and theoretical models related to the physics of faulting and earthquake generation fill the scientific literature. Drilling, sampling and downhole measurements directly within the San Andreas fault zone will substantially advance our understanding of earthquakes by providing direct observations on the composition, physical state, and mechanical behavior of a major active fault zone at hypocentral depths. In addition to retrieval of fault zone rock and fluids for laboratory analyses, intensive downhole geophysical measurements and long-term monitoring are planned within and adjacent to the active fault zone. Observatory-mode monitoring activities will include near-field, wide-dynamic-range seismological observations of earthquake nucleation and rupture and continuous monitoring of pore pressure, temperature, and strain during the earthquake cycle.

Directly evaluating the roles of fluid pressure, intrinsic rock friction, chemical reactions, in situ stress and other parameters in the earthquake process will provide opportunities to simulate earthquakes in the laboratory and on the computer using representative fault zone properties and physical conditions.

PBO is a geodetic observatory designed to study the three-dimensional strain field resulting from plate boundary deformation. This requires that plate boundary deformation be adequately characterized over the maximum ranges of spatial and temporal scales common to active continental tectonic processes. The geodetic instrumentation must provide: a) sufficient coverage of the plate boundary zone so as to capture the secular tectonic component, b) appropriate station density for detecting localized (e.g., seismic or magmatic) phenomena, and c) the necessary bandwidth (hours to decades) to detect plausible transient phenomena ranging from fast and slow earthquakes to interseismic strain buildup and post-seismic viscoelastic relaxation.

To address a range of scientific issues including plate boundary dynamics, active tectonics, and seismic and magmatic processes, a continuously recording, telmetered strain observatory will be installed along the Pacific/North American plate boundary, building upon and greatly expanding the capabilities of the SCIGN, BARD, EBAR, NBAR, SBAR, PANGA, and AKDA specialized networks.

PBO will consist of two elements. The first is a backbone network of GPS receivers to provide a long-wavelength, long-period synoptic view of the entire plate boundary zone. The network will extend from Alaska to Mexico and from the west coast to the eastern edge of the North American Cordillera. Receiver spacing will be approximately 100 km, and the data will be integrated with InSAR data (see next section), when and where available, to define the regional component of the strain field. The second element consists of focused dense deployments in areas where active tectonic phenomena occur, such as along the San Andreas fault system and around young magmatic systems. These regions require the greatest temporal resolution, and thus integrated networks of borehole strainmeters and GPS receivers will be deployed around these features with instrument spacing of 5-10 km. On the order of 1000 observing sites (strainmeters plus GPS receivers) will be required to cover the most active tectonic regions of western conterminous U.S. and southern Alaska, and about 300 GPS receivers to complete the backbone network.

A dedicated **InSAR** satellite mission carried out jointly between NASA, NSF, and the USGS will provide spatially-continuous strain measurements over wide geographic areas. This new capability will enable: a) synoptic mapping of surface displacements before, during, and after earthquakes or volcanic eruptions, b) imaging the time evolution of these geologic systems, providing unique insights into the mechanics of fault loading and earthquake rupture, c) mapping strain accumulation across broad tectonic zones, potentially highlighting zones of strain concentration, d) inferences to be made about the sources, migration, and dynamics of magma movement through a volcanic system that may lead to an eruption, and e) improvements in our understanding of the rheology of the crust and upper mantle. InSAR images also provide a tool for mapping subsidence induced by petroleum production and ground water withdrawal, as well as for studying poroelastic effects induced by fault movements and other forms of crustal deformation.

InSAR will be an essential contributor to PBO in that spatially continuous, but intermittent, InSAR images complement continuous GPS point measurements. A dedicated InSAR mission would greatly enhance PBO science objectives. The optimum characteristics are dense spatial (100 m) and temporal (every 8 days) coverage of the entire plate boundary with vector solutions accurate to 1 mm over all terrain types. Existing and planned international SAR missions cannot deliver the required data. Also, free and open distribution of these data to the scientific community is fundamental to the rapid progress of InSAR and PBO science. This has not been the case for previously planned and existing SAR missions. Thus, recognizing the leading role NASA will play in a possible SAR mission, and the long lead time for mission development, it is important that the Earth Sciences community work together with NASA, NSF, and the USGS to begin planning for a science-driven mission as soon as possible.

EarthScope core facilities provide a framework for broad, integrated studies across the Earth Sciences. Data from these facilities must be integrated with a diversity of geologic information from such disciplines as geochronology and thermochronology, petrology and geochemistry, structure and tectonics, surficial processes and geomorphology, geodynamic modeling, rock and mineral physics, and hydrogeology. All of these disciplines share a need for an Earth Science information system to integrate observations and results, manage vast arrays of data, and provide easy access to tools for manipulation and visualization of those data.

An ambitious plan like EarthScope requires significant new resources. An appropriate source of support for the facilities component of EarthScope is the MRE (Major Research Equipment) account, an NSF-wide program created to provide funding for the construction and acquisition of major research facilities that have broad scientific applicability and are beyond the funding resources of any one Directorate. MRE projects advanced by a Directorate are reviewed in a Foundation-wide competition and require approval by the National Science Board. The MRE account is funded as a separate item within the NSF budget, distinct from support for research programs. However, research budgets at the Directorate or Division level are augmented to facilitate research to be carried out with these new facilities. Previous successful MRE proposals have included airplanes, radio telescopes, and similar large-ticket items. Other scientific divisions within NSF have had successful MRE proposals in the range of tens to hundreds of millions of dollars, but EarthScope is the first MRE request to be forwarded from the Division of Earth Sciences (EAR). EAR, the GEO Directorate at NSF, and members of the steering committees of the initiatives involved have worked together to develop what will hopefully be a successful proposal. The good news to date is that EarthScope has been well received by the NSF MRE review committees. The first stage, which includes USArray and SAFOD, has received approval within NSF for consideration by the National Science Board. If approved by the Board later this year, NSF will request funding for Stage 1 in its FY 2001 budget. Funding for PBO and InSAR will be sought in subsequent years.

An initiative of EarthScope's size will require partnerships between the academic Earth Science community and many other organizations including NSF, USGS, NASA, DOE, regional networks, state geological surveys, and university consortia. International partnerships and collaborations with industry will also be important as the project matures. As a highly visible, science-driven initiative, EarthScope will play an important role in educating the public about the Earth sciences and science in general.

The challenge of developing the technical facilities is only one component of EarthScope. EarthScope provides a mechanism to unite North American geologists and geophysicists, with diverse tools and perspectives, into a broad coalition of Earth scientists devoted to a decade or more of multidisciplinary studies of the continent. In so doing EarthScope stands to expand the culture of shared and coordinated resources within the Earth sciences as a whole. It presents an exciting opportunity for development of new ideas and identification of new research targets, which, in turn, will require new theory, analysis techniques, and research tools. For EarthScope to succeed and realize its full potential, the Earth Sciences community will need to provide enthusiastic, broad-based support. Our colleagues in other disciplines regularly organize themselves to their advantage, and it is our belief that EarthScope is a golden opportunity for Earth scientists to do the same.

Additional information about EarthScope can be found at the following Internet sites:

http://www.earthscope.org
http://www.iris.iris.edu/USArray.html
http://www.iris.iris.edu/HQ/EarthScope/EarthScope.toc.html
http://www.iris.iris.edu/newsletter/EE.Fall98.web/plate.html
http://pangea.Stanford.edu/~zoback/FZD

B. Applications of L-Band and X-Band SARs to Great Lakes Ice Cover Mapping (NOAA and USCG)

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The Laurentian Great Lakes with its vast natural resource contribute significantly to economic and social activities of North America. For example, the iron ore, steel, and freight transportation enterprises tied to Great Lakes shipping directly employ over 160,000 employees with payroll of seven billion dollars. An additional 340,000 persons work in jobs indirectly tied to these industries. Ice cover in the Great Lakes, the most obvious seasonal transformation in the physical characteristics of the lakes, has a major impact on the regional climate, local commerce, and public safety.

In particular, ice cover information is valuable to:
(1) Shipping industry in extending the winter navigation;
(2) Hydropower industry in preventing damages caused by ice;
(3) Recruitment forecast for fishery management;
(4) Monitoring regional and global climate change;
(5) Winter ecology, environmental stability, wetland and deep water habitats;
(6) Hazard prediction in terms of ice jams and flooding;
(7) Indexing winter severity for public safety;

(8) Coastal erosion processes and shore structure protection;
(9) Hydraulic transport model and estimation toxic chemical distribution; and
(10) Effects on PAR (photosynthetically active radiation) and alga bloom.
(11) Timing of the opening and closing of locks connecting lower and upper lakes.

With the responsibility to collect and distribute Great Lakes information, the NOAA Great Lakes CoastWatch node at GLERL currently develops and implements ice cover mapping techniques using satellite C-band SARs such as ERS and RADARSAT. A field experiment campaign has been carried out by NOAA/GLERL and JPL for Great Lakes ice mapping algorithm development and verification with USCG ground base, helicopter, and icebreaker ship supports. C-band SAR has been demonstrated for ice cover and ice type detection and mapping as shown in Figure 1 from ERS SAR data.

Executive Order 7521 directs the U.S. Coast Guard to undertake icebreaking operations to keep open channels and harbors, within the reasonable demands of commerce. Activities primarily involve the establishment and maintenance of tracks in critical waterways and secondarily the direct assistance to keep vessels moving, preventing hazardous conditions, and extricating vessels in danger. In addition, other operations may arise from other Coast Guard missions continuing in winter months, e.g. search and rescue, maintaining aids to navigation, law enforcement, and environmental protection. At the request of the U.S. Army Corps of Engineers, the Coast Guard may undertake icebreaking, ice flushing, or escort operations in support of flood relief operations. To perform these activities, the Coast Guard requires mapping of lake ice for both strategic and tactical applications. For strategic placement of icebreaking vessels and assets, regional-coverage maps are required periodically throughout the winter ice season. For executing tactical operations, e.g. maneuvering during icebreaking, removing or replacing a buoy in ice, and assisting a beset vessel, high-resolution, local-coverage imagery and derived products in near real time are required.

In the past, side-looking airborne radar (SLAR) operated at X band was successfully used for lake ice mapping as illustrated in Figure 2. The utility of L-band SAR for lake ice mapping still needs to be investigated. However, L-band SAR with a greater penetration depth should have a potential for detecting very thick ice, which is important to USCG icebreaking operations. A combination of X and L-band SARs with some interferometric capability can provide information on a larger range of ice thickness, more ice types, and more accurate ice mapping.

Furthermore, current swath width of SAR (even operated in scan SAR modes) is typically insufficient to cover the extensive extent of the Great Lakes in a timely manner for various applications. With the synergy in operation of various future SARs such as the proposed L/X-SAR system, ENVISAT-1, ALOS, and RADARSAT-2, the timely coverage over the Great Lakes can be achieved.

Finally, there is a large community of users for Great Lakes ice cover mapping products. Potential users include NOAA CoastWatch, National Weather Service (NWS), US National Ice Center, USCG, Canadian Ice Service (CIS), Canadian Coast Guard (CCG), U.S. Army Corps of Engineers, Lake Carrier Association, and the Great Lakes Research Consortium.

Figure B-1. Great Lakes ice-type map derived from ERS-2 SAR data using the backscatter signature library (from JPL C-band radar measurements on USCG ship) together with the level-slicing classification method. On 22 March 1997, this area in Lake Superior was completely frozen. Over the lake area, red is for brash ice, yellow for rough consolidated ice floes, and green for snow covered black ice (other colors for unidentified ice type).

Figure B-2. Side Looking Airborne Radar (SLAR) X-band image of Lake Erie ice cover on 27 January 1976. The dark band along the top of the image is open water or new "thin" ice. SLAR was flown by the U.S. Coast Guard for the Extension to the Navigation Season Demonstration Study during the 1970's.

C. Applications of L/X-band SARs to Sea Ice Remote Sensing in Polar Regions (USCG)

Dr. Phil McGillivary, USCG Icebreaker Science Liaison
PH 510-437-5355 / FAX -3055
Email: pmcgillivary@d11.uscg.mil

There is a recognized need for improved remote sensing capabilities of sea ice, particularly when snow-covered or when melt pools are present for both operational and scientific reasons. From an operational standpoint, ship routing is complicated by a lack of information on snow cover of sea ice. Icebreaking ships perform best in cold, brittle ice, but snow-cover insulation from frigid arctic air can become "soft", requiring much more fuel and time for icebreaker transits. Present satellite remote sensing systems provide limited information to forecast such conditions reliably. Snow insolation of sea ice is likewise of scientific interest in affecting ocean-atmosphere heat fluxes critical to understanding global ocean and climate models, as studied during the recent large SHEBA (Surface Heat Exchange Budget of the Arctic) project. Development of combined L- and X-band radar methods for improved ice/snow remote sensing and potentially for ocean-atmosphere heat flux would thus have dual value for both operational and scientific conerns.

The shortage of L-band radar data in the arctic, as well as the lack of sea-truth studies for correlation with L- and X-band radar data in ice-covered seas make the prospect for sucessful development of improved sea ice/snow cover remote sensing methods likely. If possible, L-band satellite data produced by NASA can also be compared with Japanese L-band SAR data. Additionally, some combination of L- and X-band polarization and interferometric SAR methods could be studied to determine whether it was possible to produce useful data on ocean to atmosphere heat flux through sea ice.

USCG icebreakers routinely conduct sea-truth measurements for satellite validation, and are becoming ever better equipped to do so, with new helicopter imaging systems infrastructure capabilities, and increasing capabilities for remotely or autonomously-based (ROV or AUV-based) upward-looking under ice remote sensors. In addition to physical on-site measurements during ship operations, USCG icebreakers have previously deployed buoys for the Navy/JAMSTEC-supported Ice-Ocean Environmental Buoy Program (coordinated in part by Sus Honjo at Woods Hole Oceanographic Institution). This program is expected to continue in the future, and USCG icebreakers will likely participate in the future deployment of these buoys, which would provide frequent satellite-transmitted ocean-atmosphere heat flux data which could be correlated with maritime ice/snow satellite remote sensing characterization/heat flux studies.

We would welcome the opportunity to assist in obtaining field data on sea ice/snow as part of the planned NASA JPL coordinated ENVISAT validation program, and in particular in support of the option for including L- and X-band radar studies as part of this project, as these methods in combination may provide data useful not only for science, but for ship operational management as well. I look forward to discussing how such interactions can be undertaken in future.

D. Endorsement Letters

Alfredo E Prelat PhD
[illegible]

[illegible]
[illegible] Department
[illegible]

Phone [illegible]
Fax [illegible]
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January 6, 2000

Mr. Dan Goldin
NASA Administrator
NASA Headquarters
300 E. Street, SW
Washington, DC 20546-0001

Dear Mr. Goldin:

I sent a letter on September 16 to NASA Associate Administrator for Earth Science, Dr. Ghassem Asrar, expressing the petroleum industry's disappointment that NASA did not select a contractor for Light SAR. That letter offered petroleum industry support to solicit approval from the Oil Spill Liability Trust Fund (OSLTF) to contribute funding towards the development of a U.S. spaceborne imaging radar system that would benefit environmental management (e.g., oil spill response) and resource exploration efforts. In return for the OSLTF contribution, we requested participation in determining the technical parameters of the system, and priority in data acquisition scheduling whenever oil spill emergencies occur.

Dr. Asrar and his staff indicated that these conditions are reasonable and appropriate. At Dr. Asrar's suggestion, I began discussions with his staff on the system capabilities needed for our applications. Furthermore, Texaco hosted a workshop on December 2, 1999 in Houston, where Mr. Richard Monson of NASA, and Dr. Steven Bard, Mr. Jeffrey Hilland, Dr. Yunjin Kim, and Dr. Ben Holt of the JPL LightSAR team worked with petroleum industry representatives to reach a common understanding on the basic top-level system parameters and capabilities.

An exciting concept is evolving as a result of these discussions! The preliminary new SAR mission concept proposed by NASA/JPL received an enthusiastic response from the petroleum industry representatives. It appears that the advanced, rapid-response, high-resolution, dual-frequency, polarimetric system would meet our needs for oil spill response, environmental management, and resource exploration, and would also have features that satisfy NASA Earth Science requirements <u>and</u> meet the needs of a wide range of potential commercial applications.

A proposed new industry partnership concept is also developing, which is very promising. Having NASA lead the development and launch of the space segment leverages NASA's proven experience and past substantial investment in space imaging radar mission development. The concept that a competitively-selected commercial entity be responsible for the ground segment development and operations, and marketing the data, places the industry lead in the segment of the mission that has the greatest potential to generate revenue, and holds the most promise for fostering market development and commercialization of imaging radar information products.

With this mission and partnership concept, NASA/JPL are clearly proposing to develop the world's preeminent imaging radar system and to assure the United States leadership position in radar remote sensing!

Although there are certainly more details to be worked out, these initial steps are most encouraging, and suggest that we should take immediate measures to continue the dialogue and develop the plan suggested by the letters exchanged between myself and Dr. Asrar on September 16 and September 22.

To start, the petroleum industry representatives are jointly submitting this letter to indicate petroleum industry endorsement of collaboration between NASA and the Oil Spill Liability Trust Fund (OSLTF) in support of this essential mission. We understand NASA has been directed to submit a report to Congress by February 1, 2000, outlining a plan for moving forward with this radar mission. In support of this plan, we will begin working immediately with your staff and JPL to solicit approval from the OSLTF to co-fund approximately $175 to $200 million towards the development of this mission. We recognize that we must move quickly so this system can be launched in time to be competitive with foreign missions currently being developed and planned. We understand that NASA/JPL will be conducting a Workshop in January 2000 to apprise the wider community of radar remote imagery users of developments and solicit their suggestions. We intend to actively participate in that workshop.

We recommend formalizing the continuation of our interactions through the formation of a User Working Group for potential stakeholders in this remote sensing radar system. This group will address issues such as data rights, data policy, mission planning, and conflict resolution with the NASA/JPL project team and, if appropriate, the future commercial ground segment/operations partner.

We understand that our activity is predicated on the availability of appropriated funds for the government share of the funding. Of course, if we are successful in obtaining Congressional approval, details must be worked out of an agreement for collaboration.

Finally, we want to thank you and Dr. Asrar for your serious consideration of the approach outlined in my original letter. The radar mission being proposed is a groundbreaking pathfinder for government-industry partnership in the space arena. We look forward to working with NASA/JPL to make this exciting mission a reality.

Sincerely,

AEPrelat

Alfredo E. Prelat

cc:	Senator Lott	Mississippi	Senator Cochran	Mississippi
	Senator Daschle	South Dakota	Senator Bond	Missouri
	Senator Gramm	Texas	Senator Hutchison	Texas
	Senator Stevens	Alaska	Congressman Delay	Texas (22nd)
	Dr. Neal Lane	Director, Office of Science & Technology Policy	Ghassem Asrar	NASA
			Richard Monson	NASA
	Steven Bard	JPL		

CIPA
California Independent Petroleum Association

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January 31, 2000

Mr. Dan Goldin
NASA Administrator
NASA Headquarters
300 E. Street, SW
Washington, D.C. 20546-0001

Dear Administrator Goldin,

The California Independent Petroleum Association is a non-profit, non-partisan trade association representing approximately 500 independent crude oil and natural gas producers, royalty owners and serve and supply companies operating in California.

The association has recently become aware of the exciting new U.S. earth imaging radar satellite mission concept being developed by NASA/JPL. We feel the mission could greatly improve our nation's capabilities for emergency response to oil spills and preserving the environment.

The attached letter from Texaco outlines an innovative approach for collaboration between NASA and the Oil Spill Liability Trust Fund to co-fund this mission. CIPA endorses the collaboration approach outlined in the Texaco letter, and strongly supports NASA moving forward with development and launch of this mission.

Sincerely,

Dan Kramer

Dan Kramer
Executive Director

cc:		
	Senator Lott	Senator Cochran
	Senator Daschle	Senator Bond
	Senator Gramm	Senator Hutchison
	Senator Stevens	Congressman Delay
	Dr. Neal Lane	Ghassam Asrar
	Steven Bard	Richard Monson

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL ENVIRONMENTAL SATELLITE, DATA
AND INFORMATION SERVICE
Silver Spring, Maryland 20910

FEB 14 2000

Dr. Ghassam Asrar
Associate Administrator
NASA Headquarters
Room 5A70
300 E Street
Washington, D.C. 20546-0001

Dear Dr. Asrar:

The National Environmental Satellite, Data, and Information Service (NESDIS) was pleased to participate in the recent Workshop on NASA's Plan for Spaceborne Synthetic Aperature Radar (SAR) Remote Sensing. We are encouraged by NASA's plans for development of a SAR satellite capability in the United States. We are very interested in working with NASA on long-term plans for a fully operational SAR system to provide continuity for this valuable type of remote sensing data.

NESDIS would like to work with you to define more detailed requirements for the proposed U.S. SAR system, and will provide NESDIS representatives to the new SAR Working Group that was proposed at the workshop mentioned above. NESDIS is also willing to coordinate the gathering of U.S. Government operational SAR requirements via the NESDIS-led Interagency Ad Hoc Working Group on SAR which represents a broad mix of operational users of SAR data.

Our collaboration with NASA on gaining near real-time access to RADARSAT-1 data via the Alaska SAR Facility (ASF) has provided valuable benefits to NOAA's operational user community. SAR coverage of Alaska waters and the Arctic provide the National Ice Center with invaluable ice type and location information. Also, a recently initiated demonstration of coastal SAR applications in Alaska is providing unique high-resolution wind information to meteorologists of NOAA's National Weather Service. Both NASA and NOAA have benefited from this collaboration. For example, an additional SAR processor for near real-time processing at the ASF, purchased with Navy and NOAA funding, is also used for NASA science processing. In addition, NESDIS provided substantial funding to upgrade the ASF ground system to support both ADEOS and RADARSAT data reception. We wish to continue this mutually beneficial collaboration.

We look forward to the time when a U.S. SAR satellite system will be available to help meet the environmental monitoring requirements of the NOAA's many operational marine users, as well as the needs of the U.S. science and private sector communities.

Sincerely,

Gregory W. Withee
Assistant Administrator for Satellite
and Information Services

cc:
Nancy Foster, AA, NOS
Penny Dalton, AA, NMFS
David Evans, AA, OAR
Jack Kelley, AA, NWS

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Dr. Ghassam Asrar
NASA Headquarters
300 E. Street
Washington, D.C. 20546-0001

February 1, 2000

Dear Dr. Asrar,

In behalf of the NASA Post-2002 Cold Land Processes Mission (EX-7), and of the National Operational Hydrologic Remote Sensing Center (NOHRSC), I am writing you in support of the new U.S. Earth Imaging Radar Satellite Mission described at the recent workshop in Houston. This new Mission, with its industry partnership, directly addresses the science objectives of the EX-7 Mission, providing a single cost-effective solution to achieve multiple mission objectives. Furthermore, I anticipate that this new radar mission will revolutionize the operations of the NOHRSC, providing new opportunities to dramatically improve the National Weather Service's hydrologic forecasting of cold region rivers and floods.

The EX-7 Mission objective is to measure critical hydrologic components of the terrestrial cryosphere - cold areas of the Earth's land surface where water is frozen either seasonally or permanently. These areas are critical components of the hydrologic cycle, and interact significantly with the global weather and climate system, the geosphere, and the biosphere. The influence of seasonally frozen land surfaces extends to engineering in cold regions, trafficability for humans and other species, and a variety of hazards and costs associated with living in cold lands. The science and technology development plan for the EX-7 Mission identifies a dual-frequency (L- and X-band) polarimetric SAR as the primary sensor option for observing snow properties and the freeze/thaw state of the Earth's land surface (http://www.nohrsc.nws.gov/cline/ex7_web/ex7_home.html). The new SAR Mission concept presented by JPL is very close to the ideal sensor package identified for the EX-7 Mission. By extending the planned X-band sensor for the single-polarization to dual-polarization, the new JPL plan would fully address the sensor requirements of the EX-7 Mission.

The NOHRSC supports operational river and flood forecasting by providing remotely sensed snow and soil moisture information directly to National Weather Service forecast offices and other agencies. We currently rely on optical satellite data (GOES and AVHRR, and soon MODIS) for critical high-resolution snow cover information. However, obscuring cloud cover is a major problem in many cold land areas, especially during period of snowmelt. For example, on several days during the $4 billion snowmelt flood of the Red River of the North in 1997, the Earth's surface was obscured by cloud cover, and on those days we were unable to provide accurate snow cover data to forecasters. Elsewhere, such as the Pacific Northwest and Alaska, cloud cover is a chronic problem, and days or even weeks may pass without observing snow cover in these areas. As you well know, radar remote sensing can reduce or eliminate these effects. Therefore, we view the capabilities offered by the planned JPL SAR sensor package and the algorithm refinement planned for the EX-7 Mission as critical new developments in operational hydrology.

We look forward to working closely with JPL and industry partners throughout the planning and development process to prepare for this new Mission. We want to participate in the science development, ground segment development, and operations of this exciting new satellite, to help ensure that the Mission meets the needs of research and operational hydrology.

Sincerely,

Donald Cline

Acting Project Scientist, NASA EX-7 Mission
Chief of Operations, NOHRSC

cc:	Stephen Bard	JPL
	Paul Houser	NASA

January 27, 2000

Dr. Ghassem Asrar
NASA Headquarters
300 E Street
Washington, DC 20546-0001

Dear Dr. Asrar,

As Interim Director of the Geophysical Institute (GI) and team member of our SAR group, I wish to write in support of the concept presented for the upcoming US Sar mission at the recent workshop in Houston. You are probably aware that the GI mission in research places considerable emphasis on the fragile and ever-changing Artic environment. The Alaska SAR Facility (ASF) is a part of the GI providing critical operational support to the current SAR science community within the US as well as a growing focus on archiving and distributing SAR data collected over the Artic. We anticipate that the new SAR mission will be central to our operational and research interests, and provide new opportunities for our faculty and students.

Last fall, we began to assess the GI's requirements for a future SAR mission, incorporating the interests we have in digital elevation models, crustal dynamics, snow, ice, permafrost, hydrology and atmospheric science. Prior to the recent meeting activity, we had developed a strategy for a new SAR mission which, together with missions already announced or in flight, would meet our needs. We envisioned a new mission that was simpler and more dedicated to measurements using SAR interferometry at L band only. However, having evaluated the concept presented by JPL and considered the need for an industry lead, we are ready to join in support of this more comprehensive mission. It will have scheduling conflicts that we had hoped to avoid with a simpler satellite; however, it also has the capability to serve a much broader suite of industry needs.

The GI SAR team is keen to participate in the planning and development process which will lead to the definition of this new mission. We want to participate in science through our faculty and the ground-segment through ASF. We look forward to attending the planning meetings and providing input to the process. For your interest, a list of the working group from the Geophysical Institute is provided on the accompanying page.

Sincerely,

Roger Smith,
Interim Director

Attachment

cc: Stephen Bard, JPL
Richard Monson, NASA

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Established by Act of Congress, dedicated to the maintenance of geophysical research concerning the arctic regions.

SAR Satellite Proposal Group:

Jim Conner, DAAC Manager, Alaska SAR Facility
Ken Dean, GI Faculty, Remote Sensing
John Eichelberger, GI Faculty, Vocanology
Jeff Freymueller, GI Faculty, Crustal Dynamics
Roger Hansen, GI Faculty, State Seismologist
Verne Kaupp, Director, Alaska SAR Facility
Shusun Li, GI Faculty, SAR Specialist
Craig Lingle, GI Faculty, Antartic Ice Sheets
Buck Sharpton, GI Faculty, Remote Sensing
Roger Smith, Interim Director, GI